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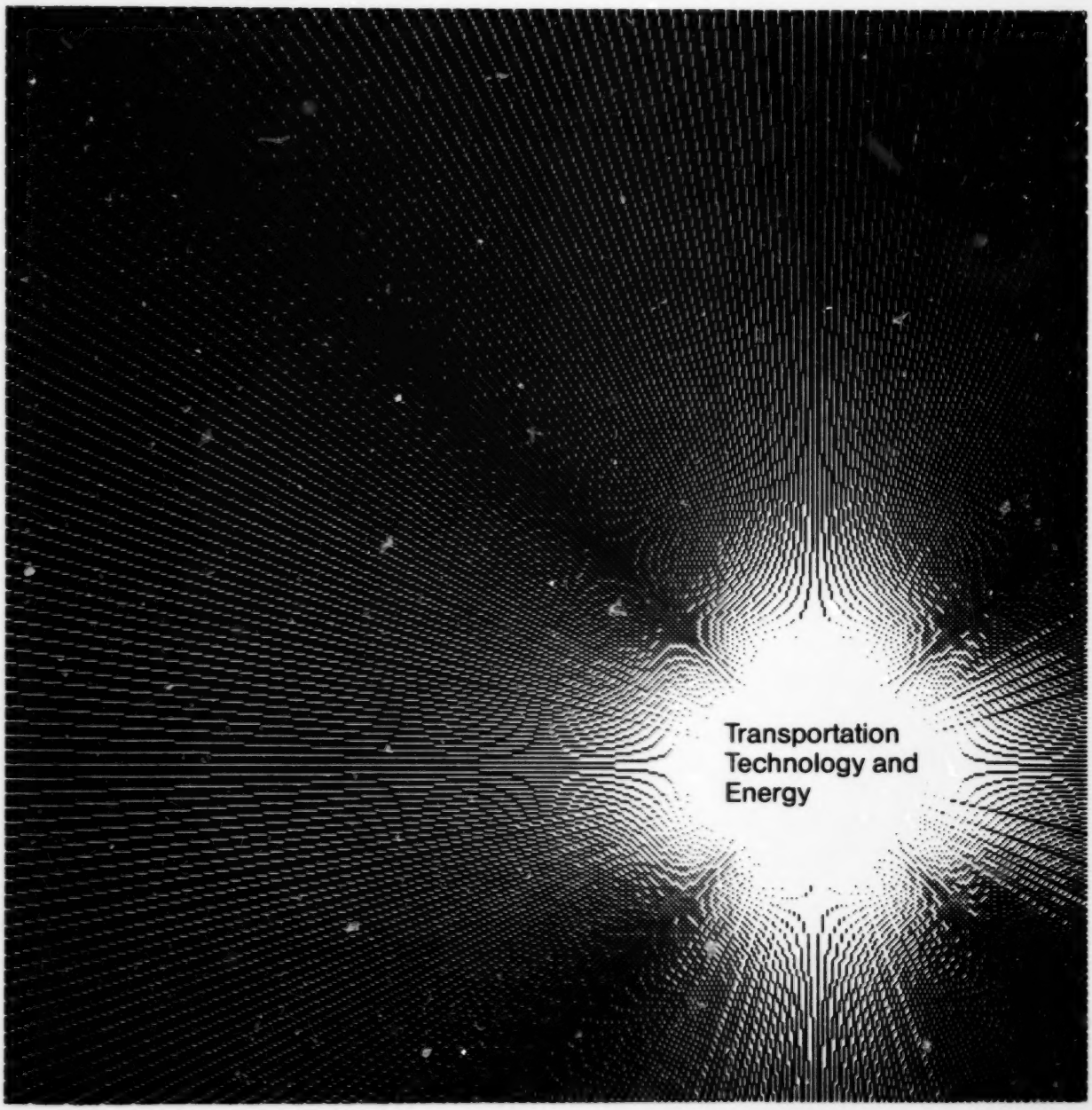
Stability of Truck Combinations



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Abstract:

This document and the accompanying video tape summarise several years of testing by MTC of the stability characteristics of vehicle combinations of the type used (or proposed for use) in commercial trucking in Ontario. The reasons for loss of control are examined together with the factors which contribute to rollover, trailer swing, and jack-knife. Comparisons are made between A-train and B-train configurations and their performance under different conditions.

Key Words: stability, truck safety, truck testing

Comments: This document is a transcript of the narration of a 20-minute VHS format video tape.

Distribution: On request

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FOREWORD

This document is a transcript of the narration of an audio/visual report summarising several years of research by MTC into the stability of truck combinations. The 20-minute video tape may be borrowed, free of charge, from:

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Drivers expect commercial vehicles to respond in a predictable way.

When a driver brakes he intends the vehicle to slow down, and when a driver steers he intends the vehicle to follow a desired path.

However, commercial vehicles sometimes respond in unpredictable ways.

Some of these unintended responses are common to both straight trucks and articulated vehicles.

Others are peculiar to articulated vehicles.

The unintended response can lead to complete loss of control of the vehicle.

A survey of commercial vehicle accidents conducted by the Ontario Ministry of Transportation and Communications revealed that loss of directional stability, such as jackknifing, usually occurred with an empty vehicle on wet roads. Rollover usually occurred with a loaded vehicle on dry roads.

It was also noted that driver actions were responsible for nearly all of the single vehicle, loss of control accidents. In about half of these accidents, speed was too fast for the prevailing conditions.

However, when more than one vehicle was involved, it was more often the fault of the driver of the other vehicle, not the truck driver.

Now let's look at the mechanics of loss of control.

Rollover is one result of loss of control.

It usually occurs when the road is sufficiently dry to resist sliding and skidding.

First let's talk about rollover in a steady turn, such as would occur on a freeway ramp.

When a vehicle follows a ramp, the force tending to cause rollover is proportional to the square of the speed of the vehicle. So if the vehicle speed is doubled, the force trying to make it roll over is multiplied by four.

The tendency to roll over is also governed by the height of the centre of gravity above the road surface.

A loaded truck having a high centre of gravity, is more likely to roll over than an empty truck. An empty truck having a lower centre of gravity is more likely to slide sideways.

This chart shows the thresholds at which various vehicles will roll over on a steady curve.

You can see that trucks, which have a high centre of gravity, roll over at a much lower threshold than a typical car.

Also, the loaded vehicle rolls over at a significantly lower threshold than the empty vehicle.

Rollover threshold on a ramp depends mostly on vehicle speed.

As the speed increases so does the tendency towards rollover.

The ramp used in this example is posted rather conservatively at 40 km/h.

Many cars would in practice negotiate this ramp quite easily at speeds as high as 60 km/h.

However, a loaded double combination vehicle taking the ramp at 60 km/h would be on the verge of rollover.

Rollover can also occur when a combination vehicle makes a rapid lane change on a straight and level roadway.

When the driver steers to make the lane change, he creates a lateral acceleration of the tractor to cause it to move sideways.

As the trailers follow the tractor through the lane change, a whip action is developed which results in higher lateral acceleration in each trailer rearward.

The lateral acceleration experienced by the last trailer of a combination can be two or more times greater than that experienced by the tractor. Therefore, it is usually the last trailer of a combination that rolls over in the manoeuvre.

Since the driver can't feel the acceleration of the last trailer, he can't directly control it. Also, its response lags one or two seconds behind that of the tractor, so when the driver realizes trailer rollover is about to occur, it's too late to take corrective action.

Rollover in a lane change is strongly related to vehicle speed and height of the centre of gravity as well as the sudden or large changes in steer which produce the forces that result in rollover.

Such steer inputs resulting in trailer rollover would usually occur only when the driver has to respond very fast to make a lane change or an evasive manoeuvre while trying to avoid an accident.

So far we've only considered the loss of control likely to occur on a dry road.

Now let's consider loss of control on a wet or slippery road.

A moving vehicle maintains directional stability by side forces generated between the rolling tire and the ground.

When the wheel is locked during braking, tire sideforce is greatly reduced with a resultant loss of control.

Even when a tire is rolling, its sideforce capability is limited, and may not always be sufficient to maintain the directional control of the vehicle.

When the sideforce capability of the front tires of an automobile or straight truck is exceeded, the vehicle will tend to plow out.

When sideforce capability of the rear tires is lost, the vehicle will tend to spin out.

In an articulated vehicle, the tendency to spin out can result either in jackknife of the tractor or in trailer swing.

Both tendencies usually occur with a lightly loaded or an empty trailer.

Jackknife is usually caused by the lock-up of the tractor drive axles.

In this situation the tractor rotates rapidly about the kingpin until the cab strikes the body of the trailer.

This happens very fast, usually in one second or less, so there is virtually no opportunity for the driver to take corrective action.

Trailer swing is an instability which develops slowly and is usually caused by lock-up of the trailer wheels.

The trailer rotates about its kingpin relative to the tractor.

The tractor may remain fully under control during a trailer swing and the driver's only indication would be by observing excessive trailer motion in the rearview mirror.

The trailer swing develops relatively slowly and the driver may be able to control it by releasing the brake.

The braking capability of the commercial vehicle is another major factor which can influence loss of control, especially on wet roads.

Commercial vehicle brakes are designed to slow and stop a vehicle when it is loaded to its maximum gross weight.

As we see here, an automobile has only a modest change in axle load between empty and loaded conditions, so its braking response is similar in both cases.

However, the drive or trailer axle load of a commercial vehicle can increase very significantly, perhaps by as much as a factor of five, between the empty and loaded conditions.

Therefore, when the vehicle is empty or lightly loaded, the brakes can become very aggressive and wheel lock can readily occur if roads are wet.

Tire inflation pressure also affects tire sideforce.

Tires are sometimes overinflated, perhaps to increase fuel mileage or reduce tread wear.

The accident survey mentioned earlier revealed that, quite commonly, tires of empty vehicles involved in loss of control accidents were inflated to pressures above those recommended by the manufacturer for a loaded vehicle.

Inflating tires in excess of the manufacturer's recommended pressure for the load carried, reduces the size of the tire-to-road contact patch.

This, in turn, reduces the amount of sideforce the tire can develop, especially on wet roads.

Overinflation may have little effect on tire sideforce when the vehicle is running loaded, but can drastically reduce the sideforce capability when the vehicle is running on wet roads.

Up to this point, discussion of stability on the wet surface has dealt with the tractor semi-trailer.

Now let's look at longer combinations.

Where the longer combination has an additional semi-trailer, it is called a B-train.

Where it has a semi-trailer with a converter dolly, it is called an A-train.

Generally speaking, those instabilities associated with tractor semi-trailers are also associated with longer combinations, but because of the additional points of articulation or hitches in the longer combination vehicle, the stability characteristics can become very complicated.

What may be a normal manoeuvre in a tractor semi-trailer can result in much greater rear trailer responses in a double combination due to the whip action shown earlier.

If a longer combination slows or swerves abruptly and there is articulation between trailers, the following trailer may tend to overrun.

In an A-train this overrun can result in sideforce capability of the dolly tires being exceeded, and dolly jackknife can ensue.

Three factors common to all these types of instability are excessive speed, too aggressive braking and too abrupt steering.

If speed is kept appropriate to the prevailing conditions, the need for aggressive braking or abrupt steering is reduced.

Now, let's look in more detail at some of the tests that have been conducted since 1976 by the Ontario Ministry of Transportation and Communications to illustrate some of the points that have been discussed.

This testing has mostly been based around the double combination vehicle shown here.

It consists of a 1975 cab-over-engine, 6 X 4 Freightliner, with two 30 ft tandem axle trailers and a single axle converter dolly. It has an empty weight of about 26 400 kg or 58 000 lb, and a loaded test weight of about 50 000 kg or 110 000 lb.

The trailers are so designed that the test vehicle can be assembled in either A-train or B-train configurations of varying lengths.

The vehicle is outfitted with devices to protect both driver and vehicle from hazard while testing to the limits of stability.

Anti-jackknife cables are installed at each articulation point to limit rotation to about 20° and to prevent development of a full jackknife or trailer swing.

Outriggers are installed on the trailers to prevent rollover.

The test vehicle is fully instrumented to measure the significant driver actions and the vehicle responses.

These measurements are recorded on board, and are also transmitted to a ground station by telemetry.

Test data is subsequently processed by computer.

The results are analysed in detail and the results of many tests have been published in reports.

The most recent series of tests was to compare the conventional converter dolly (such as would be used for an A-Train configuration) with a B-converter dolly.

The conventional dolly used in the A-train is shown in plan here.

It has a single drawbar and the dolly is free to articulate about a pintle hook on the centreline of the lead trailer.

The B-converter dolly, shown here, has two draw bars, each with a tow-eye, and uses a double pintle hook attachment to the lead trailer. This eliminates articulation of the dolly and, hence, dolly jackknife.

In this view of the two dollies used for the test, the A dolly is on the right, and the B-dolly is on the left.

The B-dolly features an automotive steering mechanism which includes an air actuated cam mechanism to centre the steer.

The testing technique was straightforward. A course, marked with cones, consisted of either a single lane-change to the left within a given gate or a lane-change to the left immediately followed by a lane change to the right, back to the original lane, that is a double lane-change.

The vehicle would be driven through this course at a series of speeds which gradually increased.

After each series of runs, the data was evaluated to determine whether speed could safely be increased.

The manoeuvres conducted in these tests would represent only an emergency situation on the highway.

They are, in no way, typical of normal driving.

The Transport Canada Motor Vehicle Test Centre at Blainville in Quebec was used for tests where a high friction surface was required.

Let's look at a series of runs with the B-converter dolly. Here a lane-change course to the left is laid out with a gate of 20 m.

This manoeuvre at higher speeds, typical of an emergency accident avoidance situation, illustrates the different vehicle response characteristics as the vehicle approaches instability.

This run is at 64 km/h, with the B-converter dolly steering mechanism set in accordance with the manufacturer's recommendations.

In this run at 70 km/h the action of the steering axle on the dolly increases lead trailer articulation, which in turn causes the second trailer to track a little out of lane.

This run is at 75 km/h and the speed has now increased sufficiently to result in an unacceptable swing into the adjacent lane. Neither trailer rolled over during this manoeuvre.

With the steering axle locked for the next series of runs, the vehicle behaves like a B-train. At 68 km/h, the trailers already swing to the edge of the lane.

And this run, also at 72 km/h, shows increased second trailer swing accompanied by rollover as seen here.

With the steering axle close to free castering even at 64 km/h the trailers are swinging to the edge of the lane.

At 70 km/h, the out-of-lane swing becomes unacceptable. Notice that there is little trailer roll. The setting of the steering axle mechanism, therefore, can have a significant effect on the mode in which the trailer becomes unstable.

Now let's look at a comparable A-train making the same manoeuvre.

At 71 km/h, the second trailer is rolling somewhat, and also sliding to the edge of the lane.

At 73 km/h, the second trailer rolls over rather violently.

Tests where a low friction surface was required were conducted at the Ontario Ministry of Transportation and Communications' test facility, at Huron Park near London.

These tests took place on the resurfaced portion of an airfield runway.

The skid number on this surface when wet is around 20 which is much more slippery than most wet highways.

Let's look again at a B-converter dolly making a similar lane change, but now with the vehicle empty and in a gate of 30 m.

The manoeuvre is made easily at 56 km/h.

This run is at 70 km/h, and a small trailer swing occurs.

This run is at 72 km/h. At this point, the tractor jackknifes on the slippery surface and reaches the limits of the safety cables. The driver loses control of the vehicle.

Rollover of the tractor and lead trailer is prevented by the articulated second trailer and the double drawbars of the B-converter dolly.

Now let's compare the A-train in the same 30 m lane change.

At 67 km/h a slight second trailer swing is seen.

At 71 km/h the trailer swing has become unacceptable.

These comparisons have illustrated the different stability characteristics between wet and dry roads, and empty and loaded vehicles, and between vehicles of different configuration. Any conclusions which may be drawn from these runs are specific to the vehicle tested and different results might be obtained for other vehicles.

Now let's watch a final series of runs, with an A-train making an evasive manoeuvre. Again, the vehicle is empty, and the road is wet and slippery.

This run at 76 km/h is successful.

This run at 76 km/h shows some trailer swing.

In this final run at 76 km/h, the dolly jackknifes at this point, and with the dolly and trailers restrained by the safety cables, the whole vehicle swings as a unit, totally out of control.

Damage from this incident was in fact minimal.

This series of runs has illustrated the very fine line between a successful manoeuvre and total loss of control. It also illustrates that the mode of loss of control may not be predictable.

In conclusion, the wise professional will avoid creating a hazardous situation by following the rules of defensive driving. This includes understanding how the vehicle will respond under certain conditions. If an emergency should occur the professional driver who knows how the vehicle's stability is affected by loads and road conditions is equipped to prevent an emergency from becoming a catastrophe.